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ACOUSTICAL INTERFERENCE BY HULL IN LORAD RECEIVING ARRAY. (U)
NOV 63 J WONG, L D MORGAN

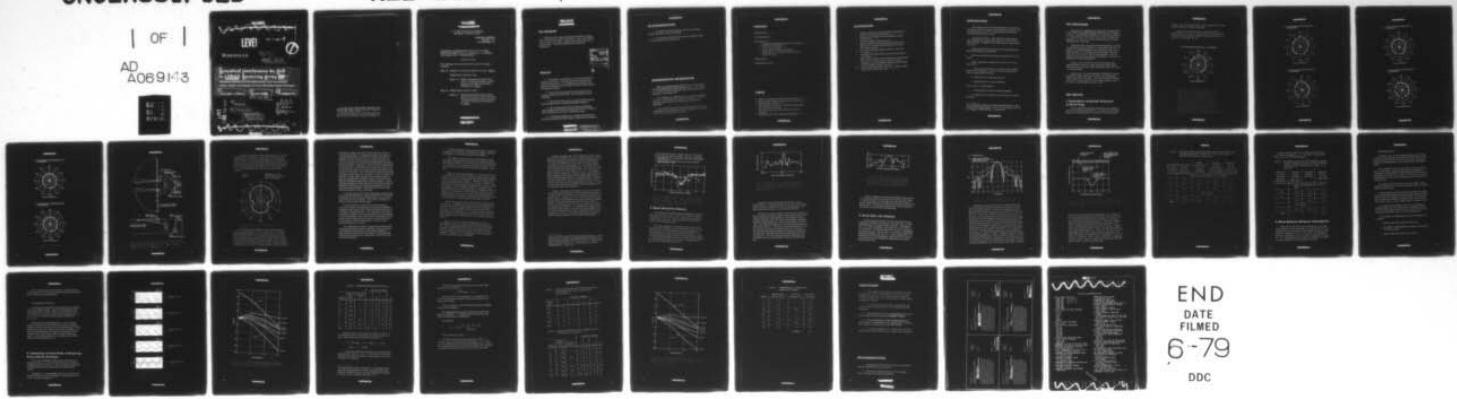
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**Acoustical Interference by Hull
in LORAD Receiving Array.** (1)

Hydrophone Amplitude And Phase Measurements And Array Directivity

Patterns Indicate That Relocation Of Array At Bow Would Improve Performance

(10)

J. Wong and L. D. Morgan

(9)

Research Report

Jul-Sep 63

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15 November 1963

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**U. S. Navy Electronics Laboratory
San Diego, California 92152**

**RESEARCH REPORT
REPORT 1197
15 NOVEMBER 1963**

**ACOUSTICAL INTERFERENCE BY HULL IN LORAD
RECEIVING ARRAY (U), by J. Wong and L. D. Morgan,
15 November 1963. CONFIDENTIAL**

E R R A T U M

The following corrections should be made on the pages indicated.

Page 26: Change two callouts on figure 10 to read: 358.5°.

Change figure caption to read:

Figure 10. Measured hydrophone phase differences. Periscope bearing of source assumed to be 000° except where indicated to be 358.5°.

Page 30: Change figure caption to read:

Figure 11. Measured hydrophone phase differences corrected for curved wavefront. Periscope bearing of source assumed to be 000° except where indicated to be 358.5°.

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THE PROBLEM

Develop an active sonar (Lorad) for the detection of submarines in deep water at ranges of 100 miles or more, and in shallow water in excess of 10 miles. Design, install, and evaluate the receiving system. Determine optimum array locations on submarines.

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RESULTS

1. The response of hydrophones is materially affected by proximity to the hull. Least interference was observed in the wing tips and at the bow. It is concluded that relocation of the present receiving array to the vicinity of Frame 3 should improve beam pattern response.
2. The array directivity patterns show high minor lobe levels as observed in earlier tests. This is attributed to hull shadowing.
3. The measured array gain is in good agreement with the gain calculated from the measured hydrophone responses.
4. The measured phase relations between hydrophones agree with phases calculated from the angle of arrival of sound, if the curvature of the wave front is taken into account.
5. A systematic difference of + 1 degree between the zero points of the periscope and the acoustic bearings was established.

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RECOMMENDATIONS

1. Investigate the hull interference effect in a systematic manner, possibly by using scale models.
2. Determine the optimum location for low-frequency linear receiving arrays aboard a submarine.

ADMINISTRATIVE INFORMATION

Work was performed under SF 001 03 02, Task 8016 (NEL E1-3) by members of the Electrodynamics Division. The report covers work from July to September 1963 and was approved for publication 15 November 1963.

R. J. Vachon, J. A. Thomson, and C. J. Krieger conducted the sea tests aboard USS BAYA, and E. A. Johnston, J. J. Cross, and D. R. Lambert operated the sound source aboard USS REXBURG.

R. P. Kempff contributed the sections dealing with phase relationships between hydrophones and the comparison of zero points of the receiving array and the periscope.

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INTRODUCTION

The response of the individual hydrophones of the Lorad receiving array to 1500-c/s pulses from relative bearing 000°, and directivity patterns at 1500 c/s using Dimus II and delay lines were determined in January 1963.¹

In the July 1963 tests, some of the above measurements were repeated with a random noise signal in a 1450 to 1550 c/s frequency band. In addition, array gain and phase measurements were made.

Certain of these data were desired in recommending optimum array locations on submarines.

The primary objectives of the tests reported here were as follows.

Using a random noise signal in the 1450 to 1550 c/s frequency band:

1. Determine the responses of particular individual hydrophones to noise pings from a source at a mean range of 2000 yards, from all relative bearings.
2. Determine array directivity patterns.
3. Determine the array gain and shading.

Using a 1500-c/s single frequency:

4. Examine phase relations between hydrophones.
5. Compare the zero points of the receiving array and the periscope.

¹Navy Electronics Laboratory Technical Memorandum 595, Beam Formation With DIMUS Mark II - Sea Trial of 24 January 1963, by C. J. Krieger, CONFIDENTIAL, 15 March 1963

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TEST PROCEDURE

The tests were conducted on 18 and 19 July 1963 aboard USS BAYA (AGSS 318) and USS REXBURG (EPCER 855) in 700 fathoms of water. The REXBURG transmitted 1/2-second pulses spaced at 2.5-second intervals, either in the 1450 to 1550 c/s band of random noise, or at 1500 c/s, using a B68CR transducer lowered to approximately 55-foot depth.

Aboard the BAYA, an omnidirectional hydrophone (11C15B2) was mounted on top of the bow as in the January 1963 test. In addition, two B27CR hydrophones were mounted 22 inches above deck at Frame 3, one on the port side and the other on the starboard side, each 24 inches from the ship centerline. They are identical to the Lorad receiving array hydrophones, and served as comparative reference hydrophones.

In parts 1 and 2 of this test, the BAYA described tight counterclockwise circles at ranges varying from about 1500 to 2500 yards from the source, which transmitted in the 1450 to 1550 c/s frequency band.

In parts 3 to 5, the BAYA followed the REXBURG, keeping the latter's relative bearing close to 000°, at an approximate range of from 900 to 1500 yards. The source transmitted both the 1450 to 1550 c/s band and the 1500 c/s single frequency in part 3, and 1500 c/s single frequency in parts 4 and 5.

TEST RESULTS

1. Hydrophone Amplitude Responses to Direct Pings

The two B27CR bow reference hydrophones were channeled one at a time through preamplifier No. 28, while the array hydrophones were measured three at a time at their own preamplifier

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outputs. These four outputs were recorded simultaneously on two 2-channel Sanborn recorders, Model 296.

Figures 1A-G show the respective differences between either the port bow reference or the starboard bow reference hydrophones and the respective outputs of array hydrophones 31, 35, 36, 42, 48, and 60 (figs. 2A, B).

A. PORT BOW HYDROPHONE MINUS NO. 31 HYDROPHONE

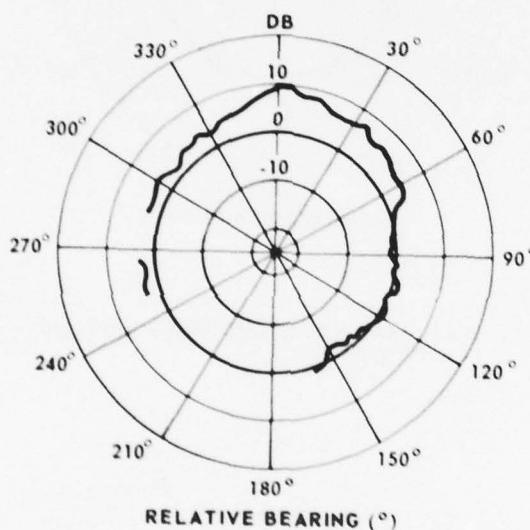
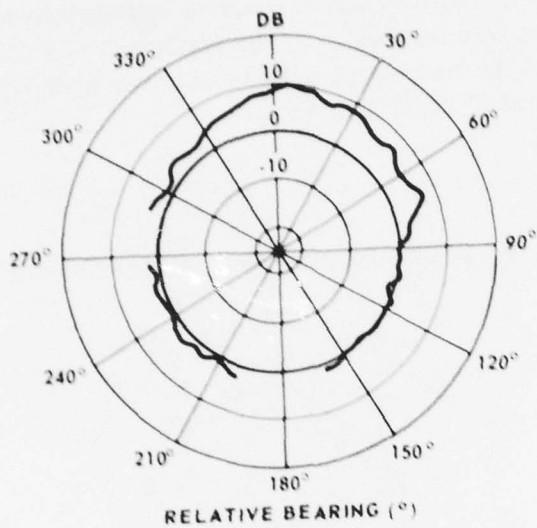


Figure 1. Relative responses of starboard bow and port bow reference hydrophones to noise pings from the REXBURG to the BAYA through 360° relative bearing. Transmitted noise bandwidth 100 c/s, centered at 1500 c/s. In each figure the constant radius circle represents zero response difference between the bow reference hydrophone and the array hydrophone. Curves outside the circle indicate that the bow hydrophone response is higher than that of the array hydrophone; those inside, that it is lower.

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B. STARBOARD BOW HYDROPHONE MINUS NO.
31 HYDROPHONE



C. STARBOARD BOW HYDROPHONE MINUS NO.
35 HYDROPHONE

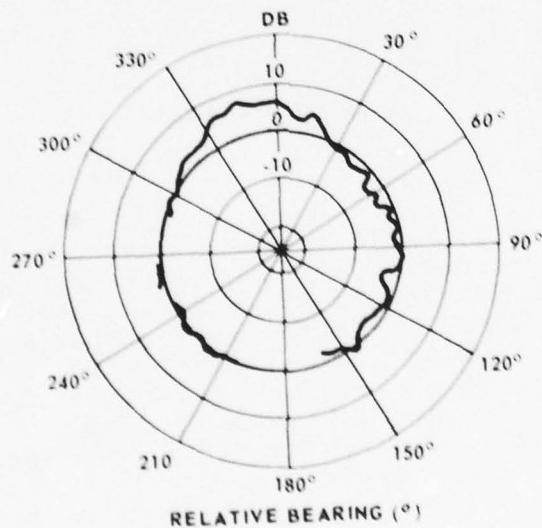
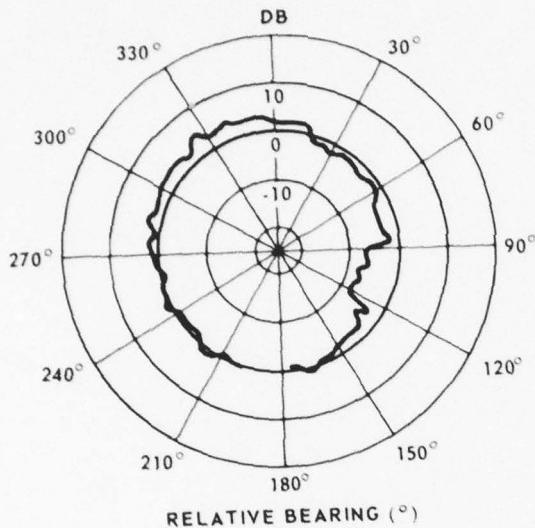


Figure 1. (Continued)

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D. STARBOARD BOW HYDROPHONE MINUS NO.
36 HYDROPHONE



E. STARBOARD BOW HYDROPHONE MINUS NO.
42 HYDROPHONE

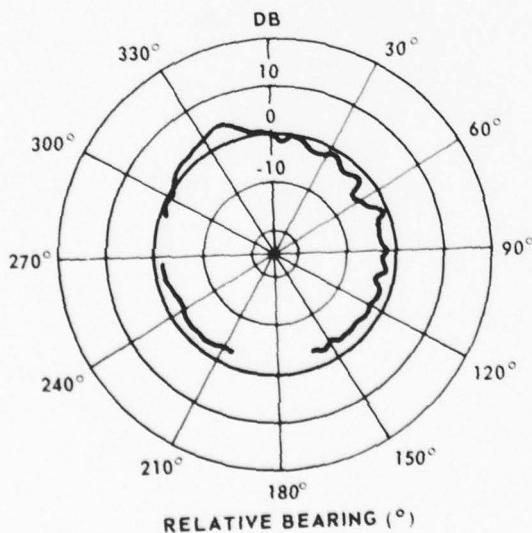
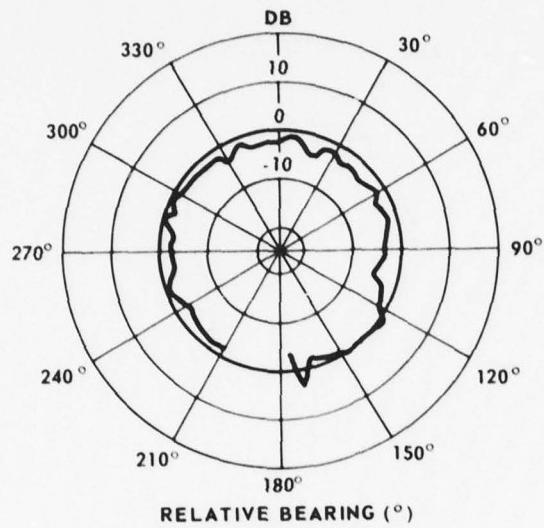


Figure 1. (Continued)

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F. STARBOARD BOW HYDROPHONE MINUS NO.
48 HYDROPHONE



G. STARBOARD BOW HYDROPHONE MINUS NO.
60 HYDROPHONE

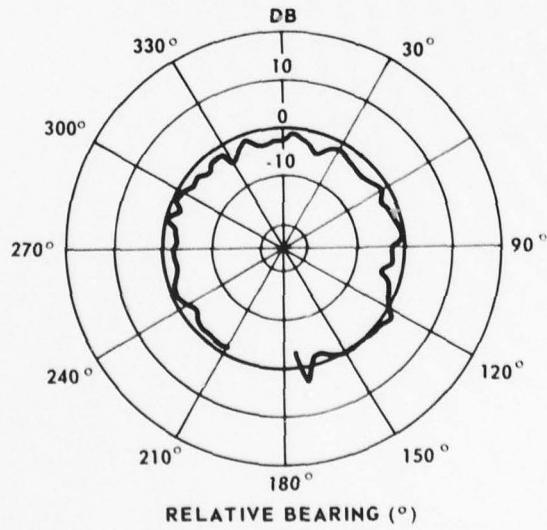


Figure 1. (Continued)

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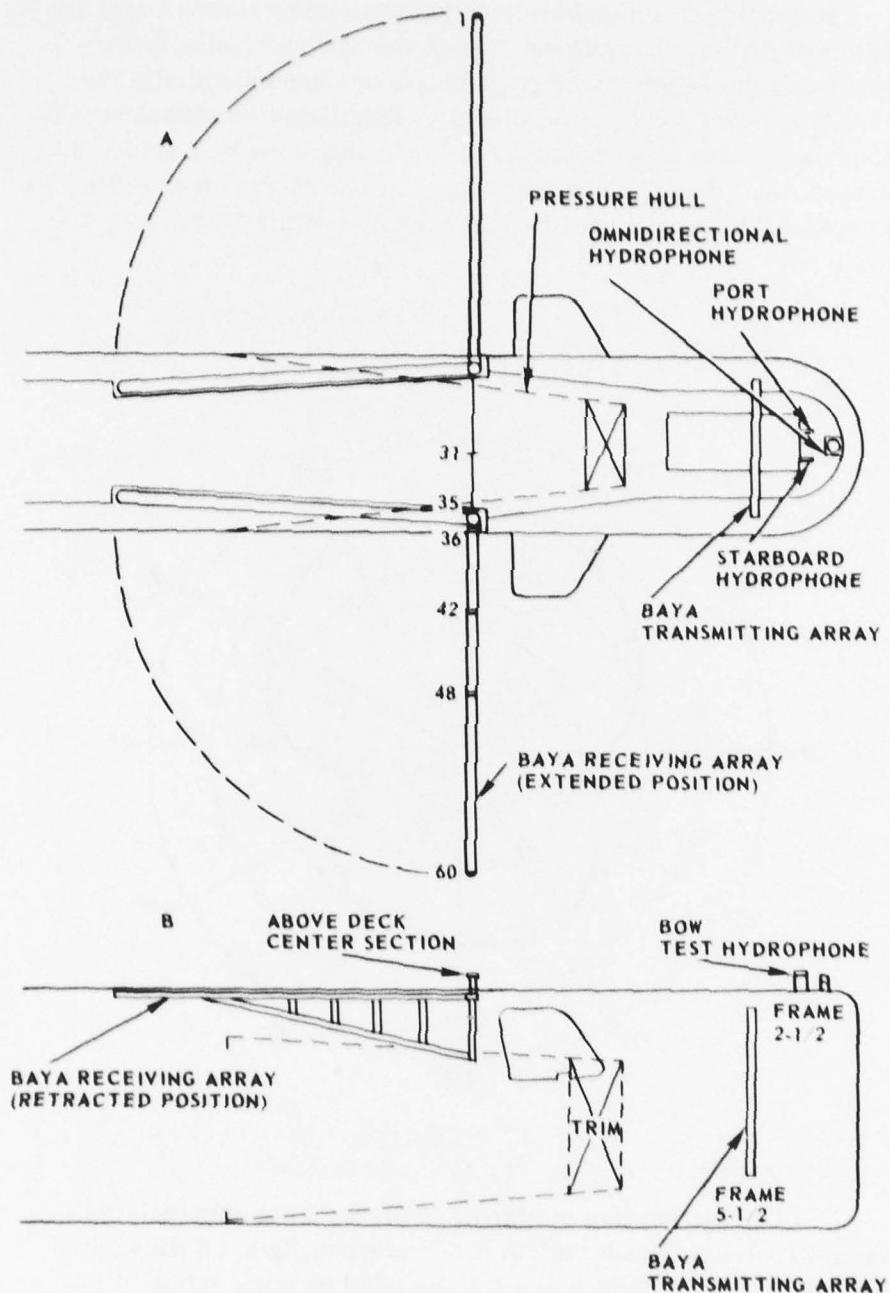


Figure 2. Locations of hydrophones used in amplitude response measurements. A. Top view of forward portion of USS BAYA. B. Side view of forward portion of USS BAYA.

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It should be remembered while considering figure 1 that the individual directivity patterns of both the bow reference hydrophones and the receiving array hydrophones are essentially the same (see fig. 3 for typical pattern). Significant comparative differences between bow and array hydrophones must be attributed to the modification of the arriving signal at one or the other of the two compared hydrophones by some portion of the BAYA'S structure.

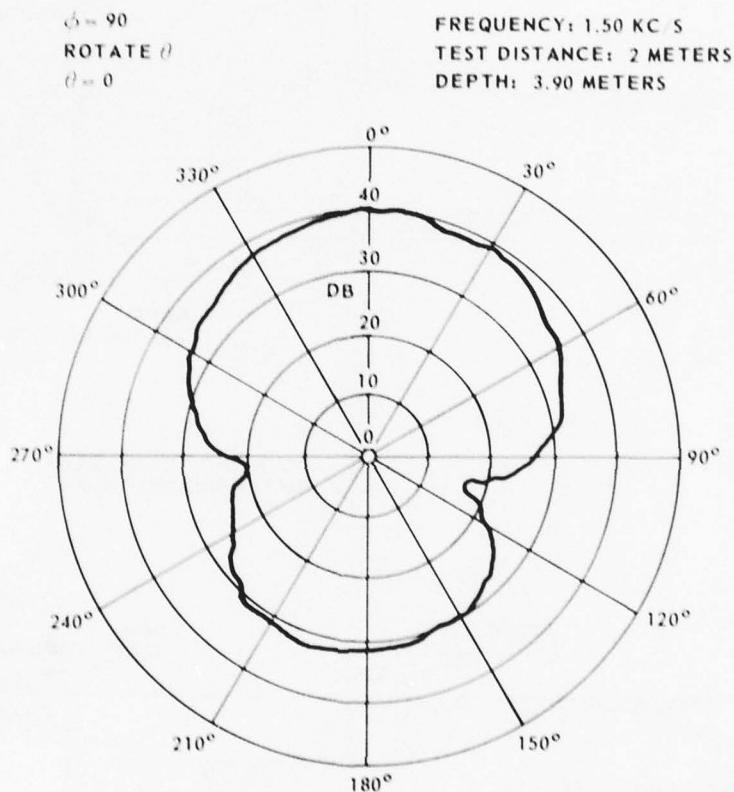


Figure 3. Typical directivity pattern of Lorad receiving array hydrophones.

For consideration of signals arriving from generally forward directions (about 290° to 070° relative) figure 2 illustrates that the bow hydrophones are not occluded by any portion of the ship's structure except by the omnidirectional hydrophone which was mounted on top of the bullnose ring. Shadow effects from this omnidirectional hydrophone should be negligible since its diameter is only about $1/4$ wavelength; however, if they exist they should be evident from about 310° to 330° relative for the starboard reference

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hydrophone, and from about 030° to 050° relative for the port reference hydrophone. It is apparent that there is no source of strong diffraction effects on these bow reference hydrophones, although a general comparative loss of response of about 3 dB relative to the nearly free-field wing tip hydrophones (discussed later) can probably be attributed to minor diffraction caused by the bow superstructure. Conversely, various portions of the BAYA'S forward structure could both occlude the signal and modify it with strong diffraction effects for reception by the central region of the present receiving array. The most probable contributors to strong attenuation are the transmitter transducer, which is air-filled and should be virtually opaque to sound, and the combined effect of numerous superstructure bulkheads, frames, and various fairly heavy and irregularly shaped items of ship's machinery. The irregular superstructure construction could also cause considerable diffraction modification to the sound traveling through it to the receiving array hydrophones, mainly those located in the center section and inboard portions of the wings.

For sound arriving from forward directions, it appears logical to attribute differences of response between the bow reference hydrophones and the array hydrophones largely to the variable response of the array hydrophones. This assumes a standard response of the bow reference hydrophone.

For consideration of sound received from the regions around 270° and 090°, the dissimilarity of individual hydrophone responses as they approach their directivity pattern nulls may be a significant contributing factor. Also, diffraction caused by the transmitter transducer may cause moderate harm to the response of the bow hydrophones, and at the same time reflections from the pressure hull and superstructure items may cause harmful diffraction effects at the array hydrophones. However, some general inferences can be drawn.

For consideration of sound arriving from aft directions the only generalized effects which are apparent are (1) the occlusion of the sound by the conning tower and (2) the possibility of a strong diffraction effect at particular angles by reflection of the sound from the pressure hull, conning tower, and aft side of the transmitter transducer.

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With these thoughts in mind, and with emphasis on the fact that figures 1A-G are plots of difference of response, not directivity patterns, we can briefly consider these figures.

The response of the bow reference hydrophones to direct noise pings from all forward directions was considerably higher than that of hydrophone #31 in the above-deck center section--that is, a maximum of 10 dB better and averaging 7 dB better in the forward sector from 330° to 030° relative bearing (figs. 1A and 1B).

Figure 1C shows that hydrophone #35, on the starboard end of the above deck array center section, has poor response in port-forward directions, indicating strong signal attenuation through the region of the transmitter transducer. Response from the starboard directions (the side on which it is located) is slightly better than that of the bow hydrophone and about equal, generally, to that of hydrophone #60 at the starboard wing tip. Responses from port-aft directions are about equal; however, although not shown in figure 1C, the signal/noise ratio for both the starboard reference hydrophone and #35 was very low in these directions indicating poorer response to the signal, probably due to a combination effect by the conning tower shadow and hull-superstructure shadow.

Figure 1D shows the same general relative response trends as figure 1C. Hydrophone #36 (fig. 1D) is the first hydrophone in the starboard wing, 20 inches outboard and 3 feet down from #35 (fig. 1C). The strong response relative to the starboard bow hydrophone, from about 090° to 120° relative bearing, is probably due to constructive interference by reflection, possibly from the superstructure which is approximately 1/2 wavelength from hydrophone #35.

Figure 1E again is similar to both figures 1C and 1D. Hydrophone #42 is 10 feet farther out in the starboard wing than #36. The small improvement in relative signal response in this location to sound from port-aft directions may indicate that the sound is beginning to bend after passing around the hull and conning tower, and that #42 is far enough out to see the beginning of this effect better than the bow hydrophone.

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Farther out on the wing, at the midpoint and 10 feet farther out than #42, hydrophone #48 shows a response generally 2 to 3 dB higher than that of the starboard bow reference hydrophone (fig. 1F) as does hydrophone #60 at the starboard wing tip, which is still another 20 feet farther out (fig. 1G). This indicates that generally these latter two hydrophones are in a nearly free sound field, limited mainly by the wing structure. One exception is the region of sound arrival from about 120° to 170° . The slightly poorer relative response of #48 and #60 in this region is possibly due to reflections from along the hull combining with the direct signal to yield slightly destructive diffraction fields at #48 and #60. The sharp bump at 170° relative is apparently not due to diffraction at #48 and #60 caused by anything on the after hull, so it may be constructive diffraction at the starboard bow hydrophone, possibly from the edge of the transducer.

Figure 4 summarizes the responses of the array elements and bow reference hydrophones to direct-path horizontal pings arriving from 000° relative bearing, as measured in January 1962,² January 1963,¹ and in this test. The solid line indicates the predicted responses (smoothed) along the array, with the assumption that the receiving array would be relocated to the vicinity of Frame 3, based on the July 1963 sea test measurements, which are indicated by the crosses. It is doubtful that a significant improvement in the responses of the inboard wing hydrophones will be achieved with the wings at Frame 3; therefore, their present responses were used, as were those of the outboard wing hydrophones which are expected to remain generally unchanged.

²Navy Electronics Laboratory Technical Memorandum 536, Lorad Receiving Array Patterns, Hydrophone Responses and Self-Noise Measurements During USS BAYA Sea Trials of 9-13 October 1961 and 25-26 January 1962, by L. D. Morgan and D. E. Bennett, CONFIDENTIAL, 5 April 1962

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△ DATA FROM SEA TESTS ON 25 JANUARY 1962; 1500-C/S PINGS USED
● DATA FROM SEA TESTS ON 24 JANUARY 1963; 1500-C/S PINGS USED
× DATA FROM 18-19 JULY 1963 SEA TESTS: 1450-1550 C/S BAND RANDOM
NOISE PINGS USED
— ARRAY ELEMENT RESPONSE USED TO CALCULATE EXPECTED
IMPROVED BEAM PATTERN

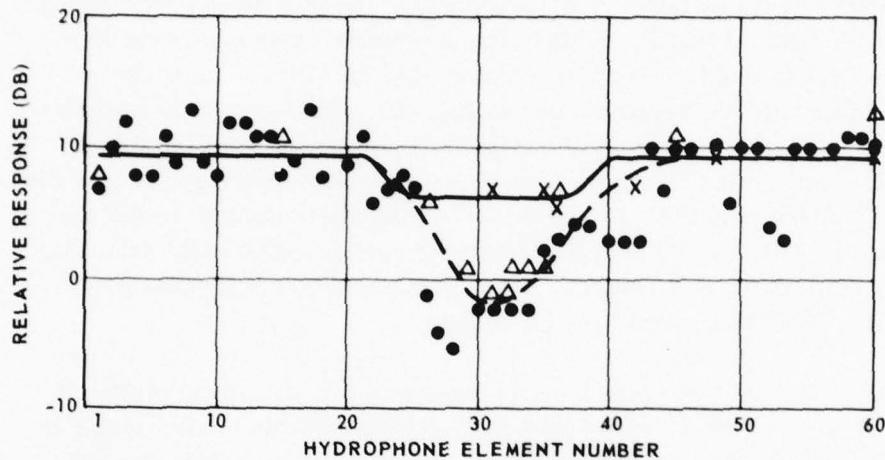


Figure 4. Responses of array elements and bow reference hydrophones to direct-path horizontal pings arriving from 000° relative bearing, showing improvement with hydrophones mounted near Frame 3, 2 feet above deck.

2. Beam Directivity Patterns

The outputs of the omnidirectional hydrophone and of three delay line beams (347° , 000° , and 013°) in response to random noise pulses (1450 to 1550 c/s) were recorded on the Sanborn recorders described earlier, after amplification and filtering in a 1250 to 1700 c/s band-pass filter.

The beam responses were normalized with respect to the omnidirectional hydrophone, by assuming that the pressure variation at the array, due to variations in range and propagation, would be the same as at the omnidirectional hydrophone. A portion of the directivity pattern of the 000° beam is shown in figure 5. Note that the main lobe was observed when the relative bearing was reported by the conning tower as 001° . The highest minor lobe level was 5 dB below the main lobe.

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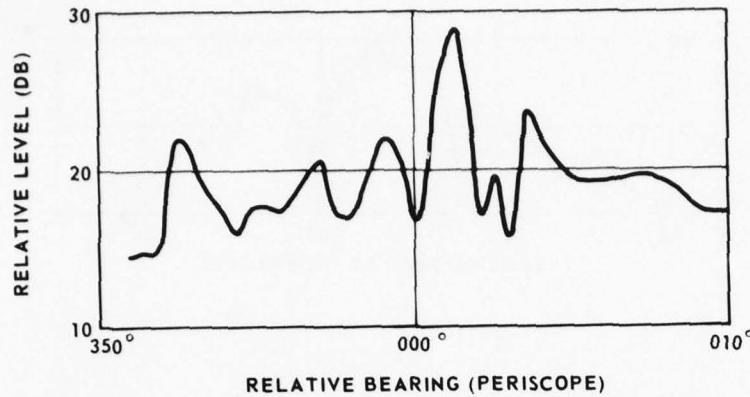


Figure 5. Lorad receiving array delay line beam (000°) directivity pattern: response to 100-c/s bandwidth random noise pings, using above-deck center section with normal amplification.

A portion of the directivity pattern of the 013° beam is shown in figure 6. Note that the main lobe was observed when the relative bearing was reported as 013.5° by conning tower. The highest minor lobe level was 5.5 dB below the main lobe.

It may be seen readily in figure 4 that the response of the ten center hydrophones in their present locations falls as much as 10 dB below that of the wing hydrophones. Ten amplifiers with individually adjustable gains were inserted between the existing pre-amplifiers and the delay lines, and directivity-pattern runs were made. The improvement hoped for in the directivity patterns was not achieved, however. The reason is not known clearly; however, the signal-to-noise and reverberation ratio was so low that in these ten center hydrophone channels the principal contribution of the amplifiers to the beam formation was waterborne noise and reverberation. The latter situation probably contributed to the degradation of the directivity patterns, which are not presented here.

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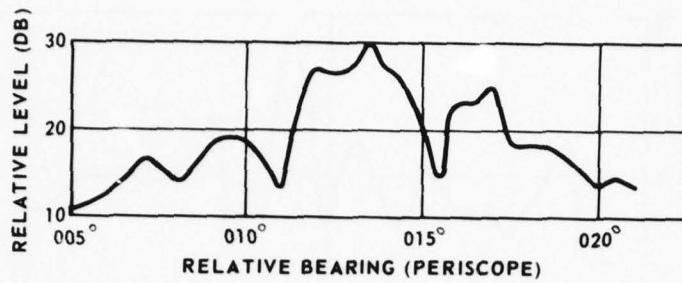


Figure 6. Lorad receiving array delay line beam (013°) directivity pattern: response to 100-c/s bandwidth random noise pings, using above-deck center section with normal amplification.

Figure 7 compares a calculated beam pattern of the present array with that expected if the array were relocated near Frame 3. The beam pattern was calculated from the array element responses shown in figure 4; the dotted curve shows the present, and the solid curve, the expected improved array element responses. Both curves are derived from smoothed data.

3. Array Gain and Shading

To measure the array gain, the received signals from one hydrophone preamplifier and the 000° beam output were recorded simultaneously on a 2-channel Sanborn recorder. Hydrophones Nos. 1, 42, and 60 with 000° beam output were also recorded as described above. The shading factors for these three hydrophones were also measured. This was done by recording one hydrophone preamplifier output and the 000° beam output simultaneously, but feeding only the selected hydrophone signal into the 000° beam delay line instead of all 60 hydrophone signals that are normally used to form a beam.

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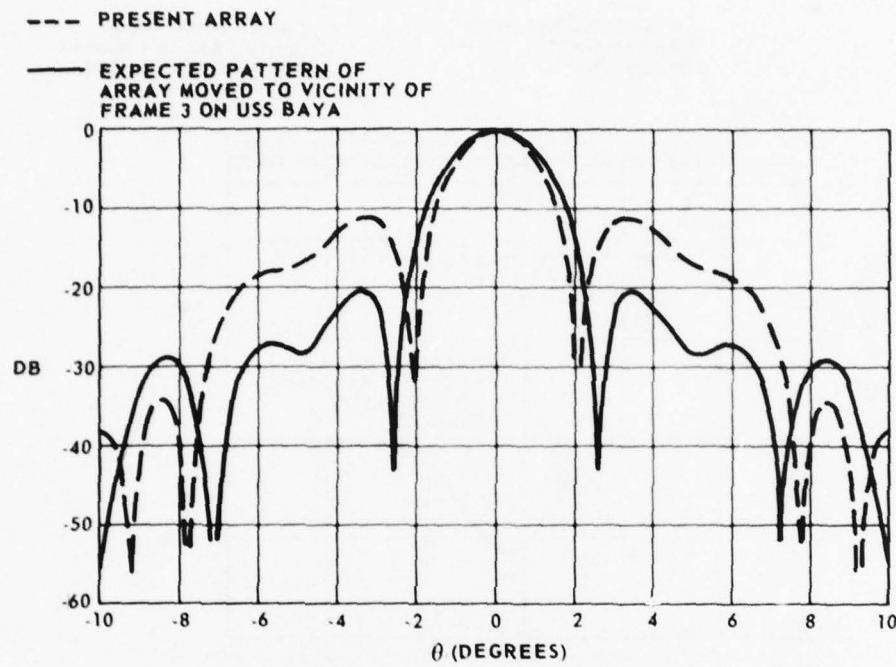


Figure 7. Calculated array beam patterns of present and proposed bow locations.

Normally the measured array gain is defined as the maximum level of the main beam lobe above the average level of the array hydrophone elements. Because of the nonuniform hydrophone element responses along the present USS BAYA linear array (see figs. 4 and 8), the measured and calculated array gain is defined here as the maximum level of the main beam lobe above the average level of the hydrophone elements near the wing tip, rather than referring to an average level of all 60 hydrophone elements. The measured array gain is corrected for electrical system gains and losses so that direct comparison can be made with the calculated array gain. The measured and calculated array gains of the 000° beam are shown in figure 8 and table 1. The calculated array gain of + 28.4 dB was obtained by using the measured relative array element responses of figure 4, reproduced in figure 8, and the theoretical shading factors. The measured array gain of 25.8 dB was obtained by averaging 23 signal pulses. This indicated that the measured array gain is 2.6 dB lower than the calculated. This difference is probably due either to the failure of the BAYA to maintain

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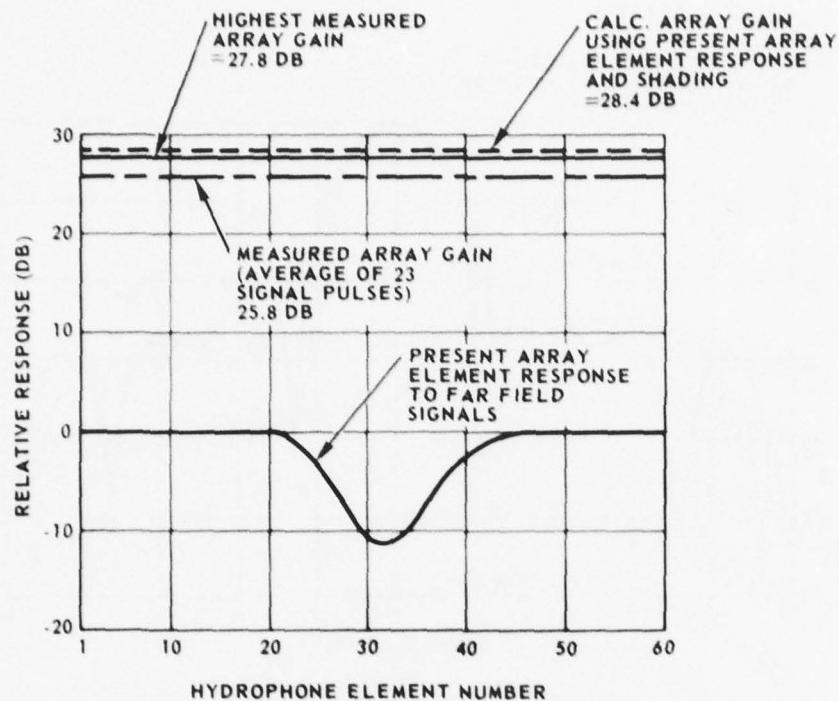


Figure 8. Mean values of measured and calculated array gain of 000° beam with ten center elements of array 2 feet above deck. USS BAYA sea tests, 18-19 July 1963.

the correct relative bearing of the REXBURG, or to a difference between the BAYA periscope bearing and the array acoustic bearing. Probably both of these factors contributed. In the beam directivity pattern measurements there is a difference of approximately 1 degree between the periscope bearing and the array. This is confirmed by phase measurements in Section 5. Figure 7 shows that if the beam is off by 1 degree, the main lobe response will be down approximately by 3.5 dB. Also, when the source was presumably closer to the correct acoustic bearing of 000° , the highest measured array gain from the 23 signal pulses is 27.8 dB (see fig. 8 and table 1). This is only 0.6 dB below the calculated value of 28.4 dB. Therefore, the measured array gain of the 000° beam is within 1 dB of the calculated value.

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TABLE 1. MEASURED AND CALCULATED ARRAY GAIN OF 000° BEAM (TEN CENTER ELEMENTS OF ARRAY ARE 2 FEET ABOVE DECK).
USS BAYA SEA TESTS, 18-19 JULY 1963.

Hydrophone No. used to determine array gain	Measured array gain (dB); avg. of 23 signal pulses	Highest measured array gain in the 23 signal pulses (dB)	Calculated array gain using present element response and shading (dB)	Difference between calc. and measured avg. array gain (dB)
Random Noise Signals (1450 - 1550 c/s Band)				
42	24.6	27.0	28.4	+3.8
60	25.5	27.0	28.4	+2.9
1	26.4	27.5	28.4	+2.0
1500 c/s Signal				
1	26.6	29.5	28.4	+1.8
Mean	25.8	27.8	28.4	+2.6

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Table 2 shows the 000° beam shading factors for three array elements, hydrophones Nos. 1, 42, and 60. The measured values are within 1 dB of the calculated.

TABLE 2. MEASURED AND CALCULATED SHADING FACTOR FOR 000° BEAM DELAY LINE OF BAYA LINEAR RECEIVING SYSTEM. USS BAYA SEA TESTS, 18-19 JULY 1963.

Hydrophone No. used to determine delay line shading factor	Measured shading factor (dB); avg. of 23 signal pulses	Calculated shading factor (dB)	Difference between calc. and measured (dB)
Random Noise Signals (1450 - 1550 c/s Band)			
42	- 2.6	- 2.6	0
60	-11.1	-10.4	+0.7
1	-11.2	-10.4	+0.8
1500 c/s Signal			
1	-11.4	-10.4	+1.0
Mean			+0.6

4. Phase Relations Between Hydrophones

During the sea tests of 18 and 19 July the phase and amplitude relations of various hydrophones were photographed from an oscilloscope single-sweep trace which sampled four signals inputs repetitively during the trace at a 1-Mc/s rate, yielding approximately 166 samples per cycle of the 1500 c/s signal for each channel. The resulting display gave virtually a simultaneous comparison of the signals out of four hydrophones at a time.

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INSTRUMENTATION

A Tektronix type 545 oscilloscope employing a type M plug-in unit (four-trace preamp) and a Wollensak Oscillo-Amaton scope camera utilizing Polaroid 3000-speed type 47 film were used for displaying and photographing various combinations of hydrophone signals.

The oscilloscope was set up for manual, single-sweep operation. In this mode, a single horizontal sweep is obtained for each depression of the RESET - MAIN SWEEP push-button on the oscilloscope. The time-base setting was at 200 μ sec/cm, giving a display of about 3 cycles of signal frequency for each sweep of the horizontal beam.

The shutter speed of the camera was set to TIME. In this setting, the depression of the shutter push button opens the shutter and the release closes it.

The type M plug-in unit permitted the simultaneous display of four independent hydrophone signals using the calibrated amplitude and time-base features of the oscilloscope. In this manner, any time (phase) or amplitude variations between any of the four input signals during a 3-cycle sample could be recorded on film.

In recording the hydrophone signals, the hydrophone pre-amplifier outputs were used rather than the hydrophone outputs. The low noise preamps boost the low level signal by 57 dB, thus eliminating the need for external low noise preamplifiers.

The procedure for photographing the received signals was as follows:

1. Camera shutter push-button was depressed.
2. The RESET - MAIN SWEEP push-button was depressed at receipt of signal.
3. Camera shutter push-button was released.

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At the conclusion of the measurements, an electrical calibration signal was fed into the preamplifier inputs and recorded on film for channel calibration purposes.

MEASUREMENTS RESULTS

Calibration measurements were made with several combinations of hydrophone elements, and all the hydrophone preamplifiers appeared to be in phase. When a 1500-c/s signal was received from 1500 yards and recorded from hydrophones Nos. 57, 58, 59, and 60, a small linear shift in phase was observed (fig. 9A, B).

When the phase of hydrophones Nos. 1, 20, 40, and 60, which are distributed over the length of the array, were photographed, the phase variations were more pronounced (fig. 9C, D) than in figures 9A and B, because the base line was longer. The calibration photograph (fig. 9E) shows that the outputs of these elements were closely in phase when an in-phase signal was applied. Phase relationships of these hydrophones are further discussed in the following section.

5. Comparison of Zero Points of Receiving Array and the Periscope

Since seven photographs had been taken of the phases of hydrophones Nos. 1, 20, 40, and 60 with the source at distances ranging from 900 yd to 1600 yd, a study was made to compare the bearing indicated from the array phases with the periscope bearing.

The phases, β_i , of hydrophones Nos. 20, 40, and 60 were read with respect to those of hydrophone #1 (considered as 0° or 360°). See table 3 and figure 10.

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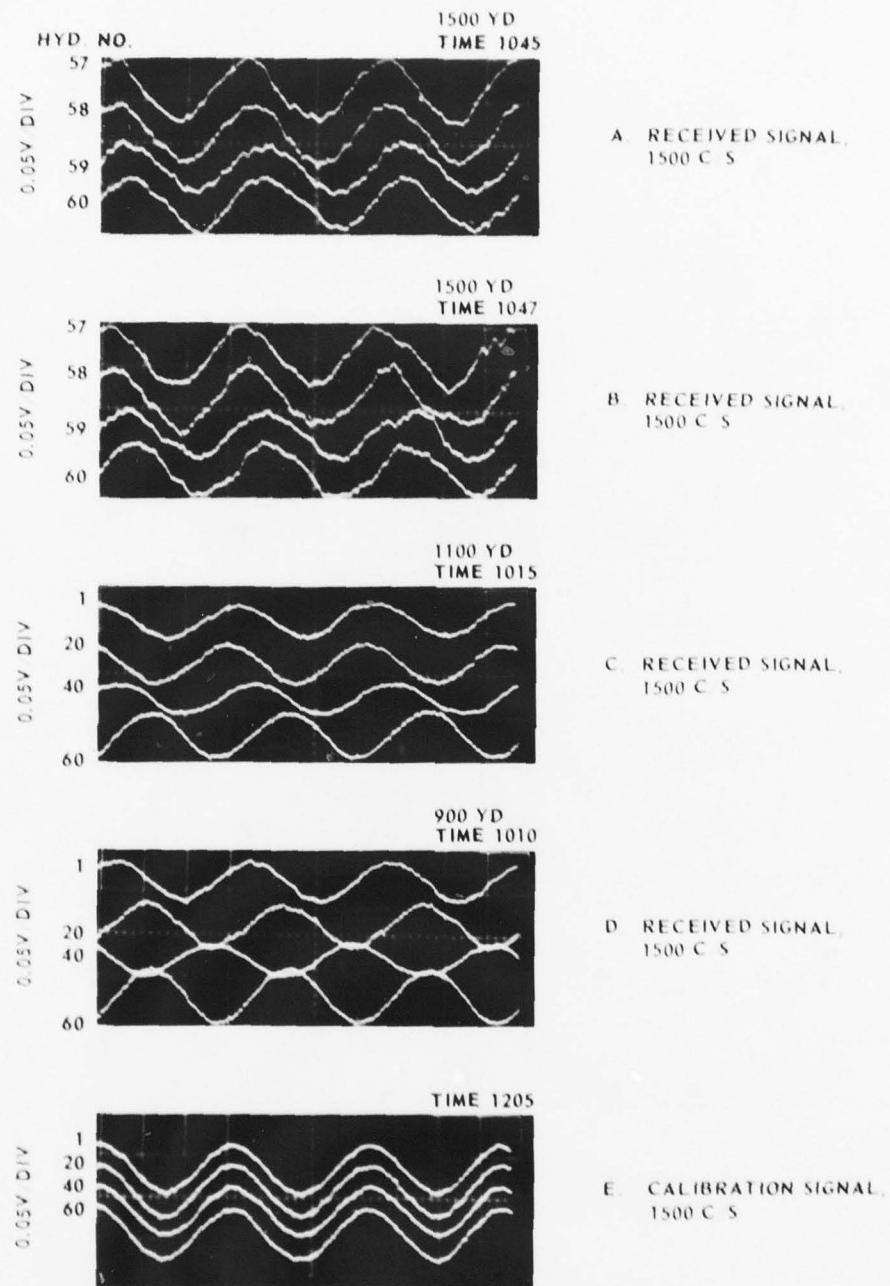


Figure 9. Simultaneous trace photographs comparing signal phases in four hydrophone channels at a time. No filters used, 200 microseconds. Relative bearing 000° except in PD, 350, 50°.

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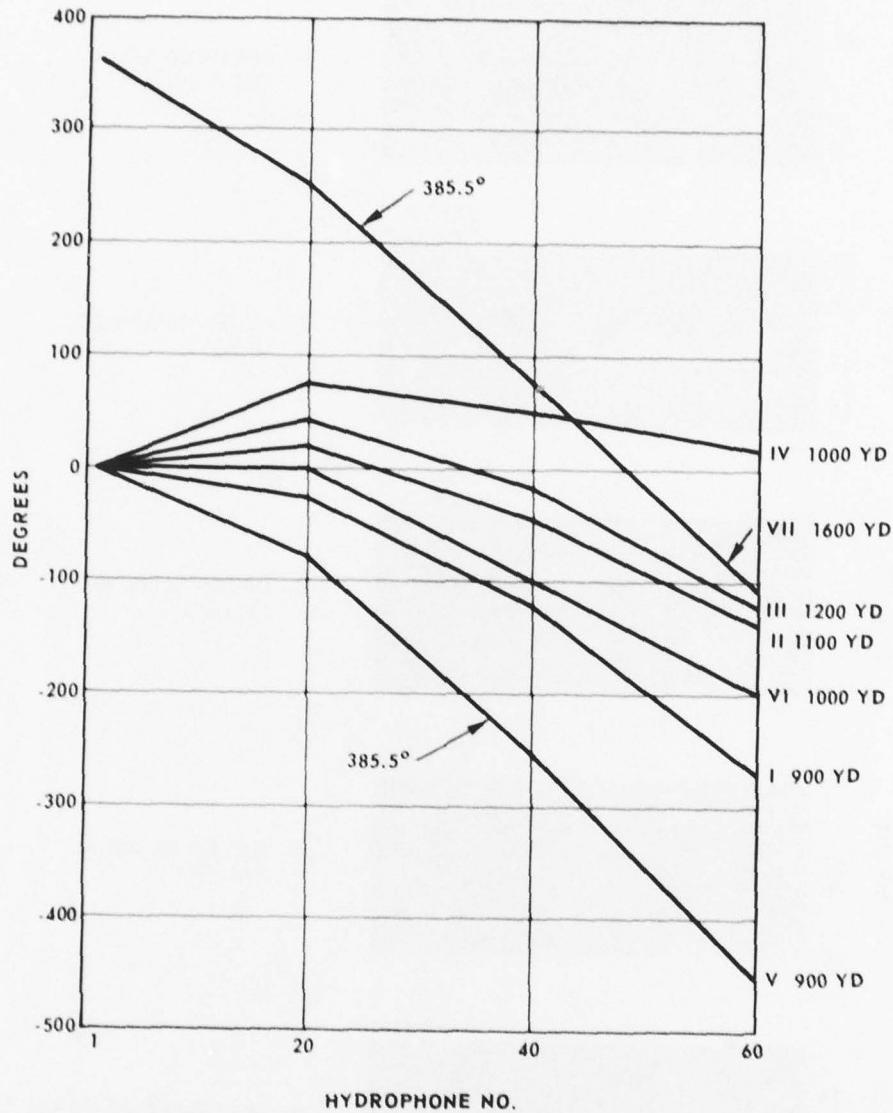


Figure 10. Measured hydrophone phase differences.
Periscope bearing of source assumed to be 000°
except where indicated to be 385.5° .

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Sample	Source Dist. (yd.)	Periscope Bearing (°)	ELEMENT NUMBER			
			1	20	40	60
I	900	---	0°	-25°	-120°	-270°
II	1100	---	0	+20	-45	-140
III	1200	000	0	+45	-15	-120
IV	1000	---	0	+78	+50	+20
V	900	358.5	0	-75	-252	-450
VI	1000	000	0	0	-100	-200
VII	1600	358.5	+360	+250	+75	-110

Since the source was at fairly close ranges, the phases at the hydrophones must be adjusted for the curvature of the wavefront. This can be expressed for the Lorad array³ as

$$\alpha_i = \pi/D \left\{ - (30.5 - i)^2 d^2 + [(30.5 - i) d \sin \theta - (30.5 - i)^2 d^2 / 2D]^2 \right\}$$

α_i is the phase difference in degrees of a curved wavefront tangent at array center ($i = 30.5$), D is the distance of the source from the array, and d the distance between elements, expressed in number of wavelengths.

³Navy Electronics Laboratory Report 1108, Simultaneous Multi-beam Phase Compensation: XII, Beam Formation With Linear, Circular, and General Arrays by Phase Compensation; Summary as of 1962, by R. P. Kempff, 7 May 1962, p. 66

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For practical purposes for this array the curvature phase differences can be written as

$$\alpha_i = -\frac{180^\circ}{D} [(30.5 - i)d]^2$$

Table 4 shows the phase difference (α_i) produced by the curved wavefront at the elements for the various distances, for relative bearing 000° .

Table 5 and figure 11 present the phase differences adjusted for the curved wavefront.

The indicated bearing was then computed by using the differences in phase ($\beta_i - \alpha_i$) of the elements taken two at a time and averaging for the six combinations.

For example:

$$\theta_{1,20} = \text{arc sin } \frac{(\beta_1 - \alpha_1) - (\beta_{20} - \alpha_{20})}{\frac{2\pi d}{\lambda} (1-20)}$$

Table 6 shows the results.

For those with no periscope bearing listed, 000° was assumed. The average difference in bearing was $\pm 0.8^\circ$, which was also indicated by the beam directivity patterns (figs. 5 and 6). It is concluded that the measured phase differences are completely accounted for by the angle of arrival and wavefront curvature.

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TABLE 4. CALCULATED PHASE DIFFERENCES FOR RELATIVE BEARING 000° DUE TO WAVEFRONT CURVATURE (α_i)

Distance (yd)	ELEMENT NUMBER			
	1	20	40	60
900	-49°	-6°	-5°	-49°
1000	-44	-6	-5	-44
1100	-40	-5	-4	-40
1200	-37	-5	-4	-37
1600	-26	-3	-3	-26

TABLE 5. PHASE DIFFERENCES AFTER CORRECTION FOR WAVEFRONT CURVATURE ($\beta_i - \alpha_i$)

Sample	Source Distance (yd)	Periscope Bearing (°)	ELEMENT NUMBER			
			1	20	40	60
I	900	---	49°	-19°	-115°	-221°
II	1100	---	40	25	-41	-100
III	1200	000	37	50	-11	-83
IV	1000	---	44	84	55	64
V	900	358.5	49	-69	-247	-401
VI	1000	000	44	6	-95	-156
VII	1600	358.5	386	253	78	-84

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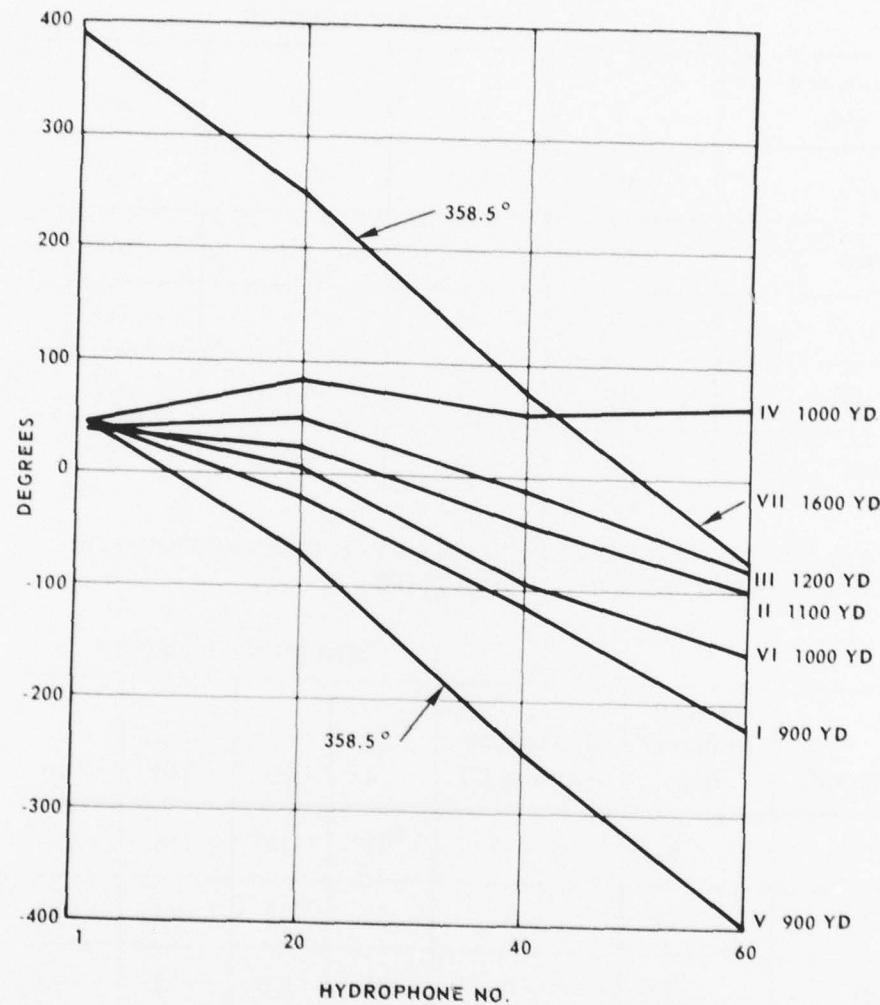


Figure 11. Measured hydrophone phase differences corrected for curved wavefront. Periscope bearing of source assumed to be 000° except where indicated to be 385.5° .

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TABLE 6. COMPARISON OF ACOUSTIC AND PERISCOPE BEARINGS

Sample	Mean Measured Bearing, M (°)	Periscope Bearing, P (°)	Differences (P - M) (°)
I	-1.4	---	+1.4
II	-0.8	---	+0.8
III	-0.6	000	+0.6
IV	0.0	---	0.0
V	-2.4	-1.5	+0.9
VI	-1.0	000	+1.1
VII	-2.5	-1.5	+1.0
AVERAGE			+0.8

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CONCLUSIONS

1. The response of hydrophones is materially affected by proximity to the hull. Least interference was observed in the wing tips and at the bow. It is concluded that relocation of the present receiving array to the vicinity of Frame 3 should improve beam pattern response.
2. The array directivity patterns show high minor lobe levels as observed in earlier tests. This is attributed to hull shadowing.
3. The measured array gain is in good agreement with the gain calculated from the measured hydrophone responses.
4. The measured phase relations between hydrophones agree with phases calculated from the angle of arrival of sound, if the curvature of the wave front is taken into account.
5. A systematic difference of + 1 degree between the zero points of the periscope and the acoustic bearings was established.

RECOMMENDATIONS

1. Investigate the hull interference effect in a systematic manner, possibly by using scale models.
2. Determine the optimum location for low-frequency linear receiving arrays aboard a submarine.

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ACOUSTICAL INTERFERENCE BY HULL IN LORAD RECEIVING ARRAY (U), by J. Wong and L. D. Morgan, 32 p.,
15 November 1963.

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The responses of the individual hydrophones of the Lord receiving array were measured, using random noise direct signal transmissions in a 1450 to 1550 c/s frequency band, from approximately 2000 yard range. Array gain and phase measurements were also made. Response was found to be materially affected by proximity to the hull. Array directivity patterns show high minor lobe levels, as observed in earlier tests; measured and calculated array gain are in good agreement. Measured phase relations between hydrophones agree with phases calculated from the angle of arrival of sound, if the curvature of the wave front is taken into account. A systematic difference of +1° was established between the zero points of the periscope and the acoustic bearings.

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